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13. ABSTRACT *(Maximum 200 words)*

The first project is "Matrix Enabled Damage Tolerance in Oxide Continuous Fiber Reinforced Ceramic Composites", PIs: Frank Zok, Carlos Levi and Robert McMeeking, funded by AFOSR. Here, the nanoindenter is being used for measuring the mechanical properties of fiber-matrix interfaces, through the so-called "fiber push-in" test. In essence, the test involves pushing an individual fiber past the surrounding matrix while simultaneously measuring the sliding displacement at the fiber/matrix interface. The resulting load-displacement response is then used to determine the toughness and the sliding resistance of the interface, using micromechanical models of the debonding and sliding. The second project utilizing the nanoindenter is "Improved Performance for MEMS-based Filters," funded by the AFOSR. The P1's are Kimberly L. Turner (UCSB) and Steven Shaw (Michigan State). In this project, the nanoindenter is used to characterize the stiffness of tethers in MEMS devices which are being developed as nonlinear components for MEMS based filters, The nanoindenter provides a direct force vs. displacement result, which is not obtainable using other measurement techniques in MEMS. Due to the inability to directly determine how much force is produced by electrostatic microactuators, and the uncertainty in MEMS fabrication techniques, it is difficult to get accurate stiffness values for the supporting spring structures. The nanoindenter is used to apply a load and get a resultant displacement curve, thereby measuring the stiffness. Out of plane loads have been obtained, howevcr in plane loads are more complex, and currently being studied. Cantilevers have also been measured.

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Final Report

ACQUISITION OF A NANOINDENTER FOR RESEARCH ON SMALL-SCALE MATERIALS AND STRUCTURES

Defense University Research Instrumentation Program (DURIP)
Fiscal Year 2002

Principal Investigators:
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Submitted to:
Air Force Office of Scientific Research
Mechanics of Materials and Devices Program
Attention: Dr. Les Lee

August, 2003

We have acquired a Triboindenter Nanomechanical Test System, manufactured by Hysitron, Inc. A complete list of component parts and prices is attached. The nanoindenter is currently being used by students, for research leading to graduate degrees, in three DOD-related projects. A brief synopsis of each of the projects along with representative results are presented below.

The first project is "Matrix Enabled Damage Tolerance in Oxide Continuous Fiber Reinforced Ceramic Composites", PIs: Frank Zok, Carlos Levi and Robert McMeeking, funded by AFOSR. Here, the nanoindenter is being used for measuring the mechanical properties of fiber-matrix interfaces, through the so-called "fiber push-in" test. In essence, the test involves pushing an individual fiber past the surrounding matrix while simultaneously measuring the sliding displacement at the fiber/matrix interface. The resulting load-displacement response is then used to determine the toughness and the sliding resistance of the interface, using micromechanical models of the debonding and sliding. Representative results from one such test are shown in Fig. 1.

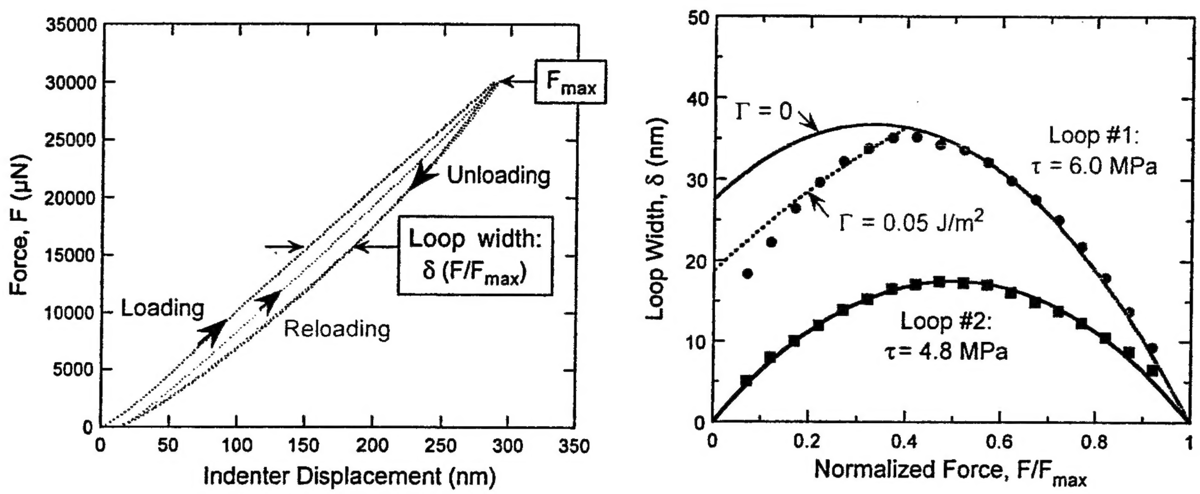
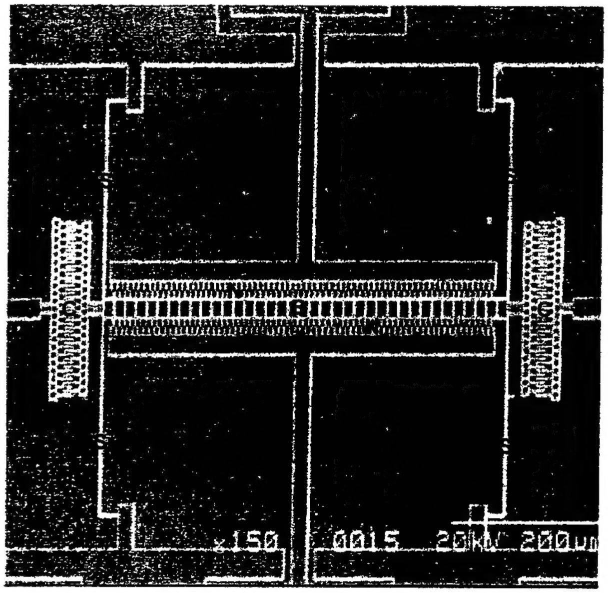
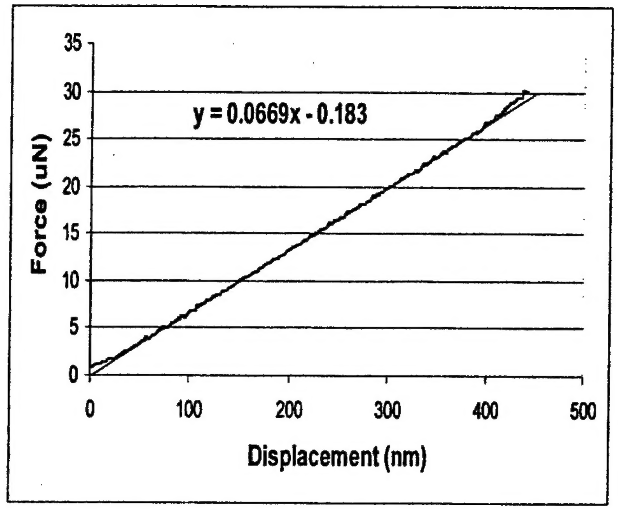


Figure 1 (a) Representative load-dispalcement curves from a fiber push-in test on a porous matrix oxide composite. (b) The results in (a) are used to obtain loop width as a funciton of load. This result, in turn, is fit to a model based on a frictional sliding stress, τ, and an interfacial fracture energy, Γ. (Solid symbols are experimental data, lines are fits of the model.)

The second project utilizing the nanoindenter is "Improved Performance for MEMS-based Filters," funded by the AFOSR. The PI's are Kimberly L. Turner (UCSB) and Steven Shaw (Michigan State). In this project, the nanoindenter is used to characterize the stiffness of tethers in MEMS devices which are being developed as nonlinear components for MEMS based filters. The nanoindenter provides a direct force vs. displacement result, which is not obtainable using other measurement techniques in MEMS. Due to the inability to directly determine how much force is produced by electrostatic microactuators, and the uncertainty in MEMS fabrication techniques, it is difficult to get accurate stiffness values for the supporting spring structures. Figure 2 shows a representative MEMS device. The springs are marked by B in the Figure. The nanoindenter is used to apply a load and get a resultant displacement curve, thereby measuring the stiffness. Out of plane loads have been obtained, however in plane loads are more complex,

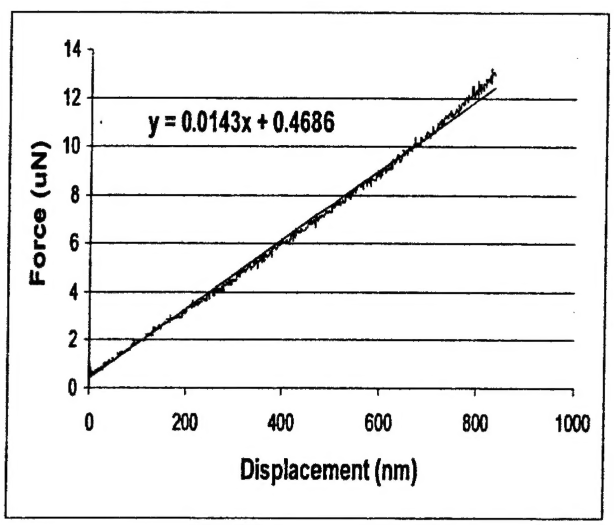
and currently being studied. Cantilevers have also been measured. Figure 3 shows force vs. displacement results for both fixed-fixed beams and fixed-free cantilevers.

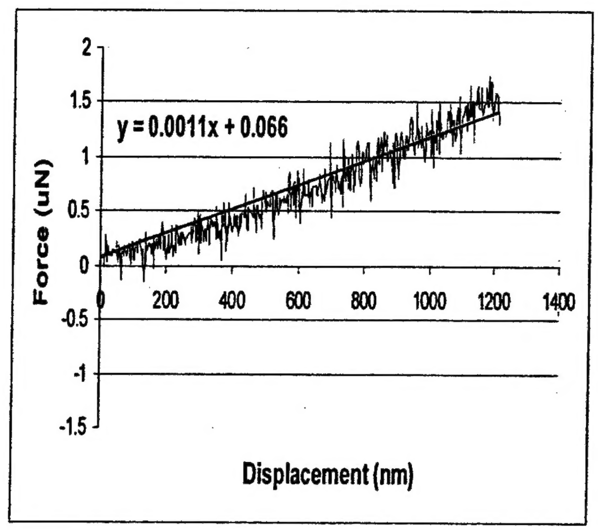




(a) (b)

Figure 2. (a) The MEMS device shown is a resonator used as an element in a filter design. The spring supports are marked as B, and are the compliant elements in the device. (b) The out-of-plane force vs. displacement curve obtained using the Hysitron Nanoindenter. As seen, the force resolution is ideal for MEMS applications. In plane measurement techniques are being investigated as well.





(a) (b)

Figure 3 (a) Force vs. displacement curve obtained from a fixed-fixed single crystal Silicon cantilever beam. (b) Force vs. displacement curve obtained from a fixed-free beam. The fixed-free beam is noisy due to slipping effects of the beam on the sample as the beam deflects downward. These effects are being investigated and minimized in future work.

The acquisition of the instrumented Nanoindentor has enabled us to begin the investigation of the mechanics of contact associated with electrical relays for MEMS devices. As with other contact mechanics, as the size of the contact area decreases, the importance of surface forces increases and with it, the propensity for "stiction" becomes more severe. Usually, MEMS devices are designed to avoid actual contact but in electrical relays this is unavoidable. In collaboration with Rockwell Scientific, who are manufacturing MEMS devices incorporating electrical relays, we are using the Nanoindentor to push on individual electrical relays and directly measure both the spring constant of the relay and the contact forces as well as the forces associated with breaking contact.

An example of a typical load-displacement curve of one of the Rockwell Scientific relays is shown in figure X. The initial stages correspond to the elastic deformation of relay spring then with further displacement the load abruptly increases as physical contact is made between the gold contacts. On unloading, the loading curve is followed in reverse but the "break" in contact occurs at a smaller displacement with an immediate increase in the load indicating an attractive "striction" between the contacts. Through experiments enabled by the nanoindentor, such as these, the detailed mechanics of MEMS contacts are being explored.

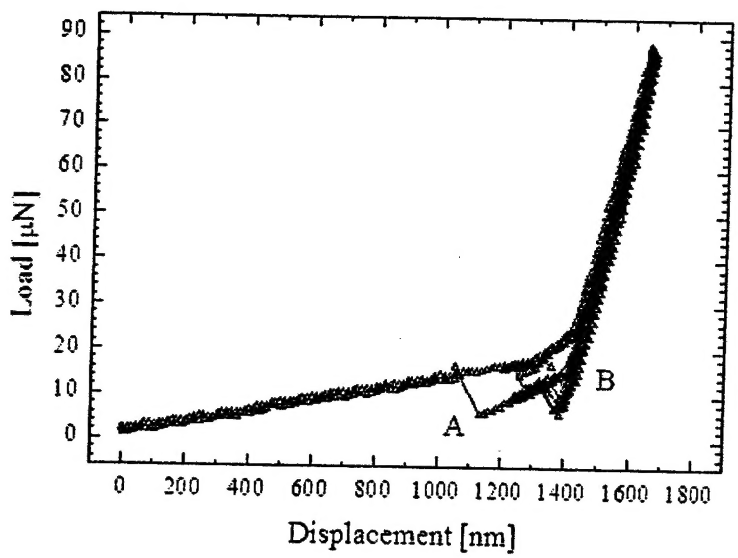


Figure 4. A series of load-displacement curves for loading and unloading a MEMS electrical relay as the surfaces are separated. The stiction associated with breaking contact is seen in the abrupt increases in load at A. The stiction increases with loading cycles and progresses from breaking the initial contact at B to the final one at A.

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Purchase of equipment from Hysitron, Inc.

Triboindenter, 110V, Imaging Nanamech. Test Sustem	$187,045.00
TriboAE, Normal force	$32,050.00
Tip, Cube Corner, AE, 90 deg. Acoustic Emission	$2,675.00
Offline Software	$11,085.00
Transducer Assy, High Force	$18,000.00
Tip, Cubecorner, 90 deg.	$1,240.00
Tip, Conical 5um, 60 deg.	$1,933.91
Academic Discount	($35,000.00)
Plus 7.75% Tax	$16,974.74
Total	$236,003.65
AFOSR Contribution	$190,812.00
Cost Sharing	$34,700.00
Prof. N. MacDonald's Contribution	$10,491.65
	$236,003.65